UNIVERSITI PUTRA MALAYSIA

NITROUS OXIDE EMISSION FROM AN UPLAND CROPPING SYSTEM IN THE HUMID TROPICS

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FP 2001 28

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Thesis Submitted in Fulfilment of the Requirement for the Degree of Doctor of Philosophy in the Faculty of Agriculture
Universiti Putra Malaysia

March 2001

To My Respected Parents

Shamina Khatun and Late Munshi Sultan Ahmed

and

Beloved Wife, Lucky

Dearest Daughter, Chaity

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

NITROUS OXIDE EMISSION FROM AN UPLAND CROPPING SYSTEM IN THE HUMID TROPICS

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Nitrous oxide (N_2O) emission to the atmosphere has a great implication on global climate change. Agricultural soils seem to be its major source, though little attention is given to the soils and upland cropping systems of the humid tropics. Thus, laboratory experiments were carried out to study the impact of N sources, moisture regimes and soil types on N_2O production A field experiment was conducted to measure N_2O emissions from a maize-groundnut cropping system managed with different N sources. The laboratory incubation study using an Ultisol showed a maximum N_2O flux of 2379 µg N_2O-N kg^{-1} soil d^{-1} with chicken manure application at 60% water-filled pore space (WFPS). Application of potassium nitrate, groundnut residue and urea resulted in smaller production rates (615 - 699 µg N_2O-N kg^{-1} soil d^{-1}). Addition of ammonium sulfate and maize residue produced the lowest rates, 229 and 246 µg N_2O-N kg^{-1} soil d^{-1}, respectively. In general, the total N_2O production in 25 days increased with decrease in C/N ratio of the organic N sources. The loss of

applied N through N_2O emission was higher from inorganic N (3.5-8.6%) than from organic N sources (1.6-6.7%). It could be because of denitrification during the initial period of incubation with readily available mineral N, compared to slower release from organic N sources. Although smaller N_2O production (26.6-38.7 μg N_2O-N kg^{-1} soil d^{-1}), the fluxes increased with increase in soil moisture content. The relatively drier soil (20% WFPS) acted as a sink. The total N_2O production in the soil with 40, 60 and 80% WFPS increased by 46, 58 and 72%, respectively over the soil with 20% WFPS. Liming the acid soils, similar to the addition of urea and chicken manure, increased the soil pH to around 5.5, stimulating nitrate accumulation after a lag period and N_2O production concurrently. The N_2O productions were not affected by the soil acidity; the total production correlated positively with pH, CEC, organic C and N content of the soils and negatively with water-soluble organic carbon (WSOC). Under the maize-groundnut crop rotation, addition of chicken manure resulted in a maximum N_2O flux of 9889 μg N_2O-N m^{-2} d^{-1} within the first one week after application during the fallow period i.e. after the groundnut crop cycle. The residual effect is also exhibited during the maize cultivation, showing a higher N_2O flux (4053 μg N_2O-N m^{-2} d^{-1}) than the plots treated with only inorganic N fertilizer. A lower N_2O flux or negative flux during fallow periods occurred probably due to small availability of substrates and/or low WFPS (<40%). The added N sources retained in the soil for 2 to 3 weeks, matching with the N_2O emission. The high coefficients of variation of N_2O emission under both crop covers showed no clear diurnal variations of N_2O flux. The temporal variability was large, showing a higher emission during the fallow period after addition of chicken manure as well as during maize cultivation after application of N fertilizer. The highest total emission (1.82 kg N_2O-N ha^{-1}) during maize period was in the plots with chicken manure and addition of half the

amount of recommended N fertilizer. This depicted an influence of chicken manure, which was applied before cultivation of the maize crop. The estimated annual emission was 3.94, 1.90 and 1.41 kg N_2O-N ha^{-1} from the plots treated with chicken manure plus crop residues and N fertilizer, crop residues and N fertilizer, and N fertilizer only, respectively. The estimated fertilizer-induced N_2O emission factor (1.06%) was lower than the generally accepted standard value (1.25%) currently being used by the Intergovernmental Panel on Climate Change. This study suggests that supply of chicken manure to crop fields could be an important potential source of N_2O.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMERUWAPAN NITRUS OKSIDA DARIPADA SISTEM PENANAMAN TANAH TINGGI DI KAWASAN LEMBAB TROPIKA

Oleh

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Mac 2001

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Nitrus oksida (N_2O) mempunyai implikasi yang besar terhadap perubahan cuaca global. Tanah pertanian merupakan punca utama pengeluaran N_2O walaupan masih kurang perhatian diberikan terhadap tanah dan sistem pananaman di kawasan tropika. Berdasarkan permasalahan tersebut kajian di ladang dan makmal telah dijalankan untuk mengkaji kesan sumber N, kelembapan tanah dan jenis-jenis tanah terhadap penghasilan N_2O dan pemeruwapannya daripada sistem tanaman bergiliran jagung-kacang tanah dengan aplikasi sumber N yang berbeza. Kajian inkubasi di makmal menggunakan tanah *Ultisol* menunjukkan fluks maksimum N_2O (2379 μg N_2O-N kg^{-1} tanah $hari^{-1}$) terjadi apabila ditambah tahi ayam pada 60% ruangrongga isian air (water-filled pore space, WFPS). Penambahan kalium nitrat, sisa kacang tanah dan urea menunjukkan kadar penghasilan N_2O yang rendah (615 - 669 μg N_2O-N kg^{-1} tanah $hari^{-1}$). Penambahan ammonium sulfat dan sisa jagung menghasilkan N_2O yang lebih rendah, iaitu masing-masing 229 dan 246 μg N_2O-N kg^{-1} tanah $hari^{-1}$. Penghasilan jumlah N_2O, dalam 25 hari meningkat dengan penurunan nisbah C/N sumber N organik. Peratus kehilangan baja N melalui penghasilan N_2O adalah lebih

tinggi untuk sumber N tak organik (3.5-8.6%) berbanding sumber N organik (1.6-6.7%), disebabkan berlakunya proses denitrifikasi pada permulaan tempoh inkubasi dengan adanya N mineral tersedia berbanding permineralan N yang berlaku dari baja organik. Walaupun penghasilan N_2O rendah (26.6-38.7 μg N_2O-N kg^{-1} tanah $hari^{-1}$), fluksnya meningkat selaras dengan peningkatan peratus kelembapan tanah apabila dibandingkan dengan tanah yang lebih kering (20% WFPS) yang bertindak sebagai penjerap N_2O. Penghasilan jumlah N_2O pada 40, 60 dan 80% WFPS masing-masing meningkat sehingga 46, 58 dan 72% pada 20% WFPS. Pengapuran tanah berasid, sama seperti penambahan urea dan tahi ayam, telah meningkatkan pH tanah sehingga 5.5 dan meningkatkan pengumpulan nitrat selepas tempoh lamban dan penghasilan N_2O. Pemeruwapan N_2O tidak dikawal oleh keasidan tanah; jumlah penghasilan N_2O berkorelasi secara positif dengan pH, CEC, C organik dan kandungan N tanah dan berkorelasi negatif dengan karbon organik larut air (WSOC). Dalam sistem tanaman bergiliran jagung-kacang tanah, penambahan tahi ayam menyebabkan fluks N_2O maksimum (9889 μg N_2O-N kg^{-1} tanah m^{-2} $hari^{-1}$), dalam masa satu minggu semasa tempoh tanpa tanaman, iaitu selepas tanaman kacang tanah. Kesan sisa tahi ayam dapat dilihat semasa penanaman jagung iaitu dengan kadar pemeruwapan N_2O yang tinggi (4053 μg N_2O-N kg^{-1} tanah $hari^{-1}$). Fluks N_2O yang rendah atau fluks negative semasa tempoh tanpa penanaman terjadi disebabkan substrat yang rendah atau WFPS yang rendah (<40%). Sumber N yang ditambah, kekal di dalam tanah sehingga 2–3 minggu berpadanan dengan pemeruwapan N_2O. Variasi koefisien yang tinggi bagi fluks N_2O untuk untuk kedua-dua tanaman menunjukkan tiada variasi fluks diurnal N_2O yang jelas. Variasi temporal adalah besar, dan menunjukkan pemeruwapan yang tinggi semasa tempoh tanpa tanaman, iaitu selepas penambahan tahi ayam serta semasa penanaman jagung selepas penambahan baja N. Jumlah pemeruwapan N_2O tertinggi dalam tempoh penanaman jagung (1.82 kg N_2O-N ha^{-1}), adalah dalam plot penambahan tahi ayam bersama separuh daripada kadar baja N yang disyorkan (75 kg N ha^{-1}), mungkin disebabkan kesan penambahan tahi ayam sebelum penanaman jagung. Pemeruwapan tahunan yang dicatatkan adalah 3.94, 1.90 dan 1.41 kg N_2O-N ha^{-1} daripada plot penambahan tahi ayam bersama sisa tanaman dan baja N, plot sisa tanaman bersama baja N, dan plot baja N sahaja. Faktor pemeruwapan N_2O disebabkan penambahan baja (1.06%) yang dikira daripada kajian ini, adalah lebih rendah daripada nilai yang digunakan sekarang mengikut garis panduan 'Intergovernmental Panel on Climate Change' iaitu 1.25%. Keputusan ini menunjukkan bahawa penambahan tahi ayam di kawasan tanaman adalah berpotensi sebagai punca utama pemeruwapan N_2O.

ACKNOWLEDGEMENTS

The author extends his deep sense of gratitude to the Chairman of Supervisory Committee Associate Professor Dr. Rosenani Abu Bakar, Department of Land Mangement, Universiti Putra Malaysia (UPM) and the Co-Chairman of the Supervisory Committee Professor Dr. ir. Oswald Van Cleemput, Faculty of Agricultural and Applied Biological Sciences, Ghent University, Belgium, for their scholastic and active guidance, valuable advice and tutelage during the research work and preparation of his dissertation.

A sincere gratitude also goes to the members of the Supervisory Committee Professor Dr. Shamshuddin Jusop and Dr. Che Fauziah Ishak, Department of Land Management, UPM, for their technical advice and valuable guidance at various stages of research and critical reviewing of his dissertation.

He gratefully acknowledges the Ghent University, Belgium and Universiti Putra Malaysia and the respective Governments for providing the scholarship and research facilities under a Ph.D Twinning Programme. He is indebted to the Bangladesh Institute of Nuclear Agriculture (BINA) and the Government of the Peoples' Republic of Bangladesh for providing deputation and immense help to accomplish his degree.

The author wishes to express his appreciation to Professor Dr. G. Stoops, Co-ordinator of the Twinning Programme and Dr. ir. Pascal Boeckx, Laboratory of Applied Physical Chemistry, Ghent University, Belgium for their assistance and suggestions.

He desires to extend his appreciation to Associate Professor Dr. Siti Zauyah Darus, Dr. Anuar Abdul Rahim, Mr. Peli Mat, Associate Professor Dr. Aminuddin Hussin, Associate Professor Dr. Zaharah Abdul Rahman and Associate Professor Dr. Mohd. Khanif Yusop of UPM for their help and moral supports.

He is profoundly indebted to the technical staff of the Department of Land Management of UPM, especially to Mr. Mutuviren, Mrs. Faridah, Mrs. Rusnah, Mr. Sabri, Mrs. Norhayati, Mr Shukri, Mrs. Fauziah, Mrs. Faridah (MSTB) and other staffs of the Soil Science Laboratories for their co-operation during my research work..

The author is thankful to all of his friends and colleagues of national and international origins, especially to Mr. Amir Hamzah for translating the abstract, and to Dr. M.A. Satter, Mr. M.A. Baset Mia, Mr. Humayun Kabir Mithu, Mr. Shibli Russel for providing an amiable atmosphere and encouragement.

He expresses his high regard to his mother and late father for being the pillar, who inculcated academic perseverance. He is highly grateful to his loving wife, Ferdousi Begum Lucky and sweet daughter, Dimitra Khalil Chaity for their patience, sacrifices and a never-ending inspiration.

I certify that an Examination Committee met on 2nd March 2001 to conduct the final examination of Mohammad Ibrahim Khalil on his Doctor of Philosophy thesis entitled "Nitrous Oxide Emission from an Upland Cropping System in the Humid Tropics" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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I hereby declare that this thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

MOHAMMAD IBRAHIM KHALIL

Date: 09/03/2001

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CHAPTER I

INTRODUCTION

Nitrogen, an essential element for plant growth, plays a vital role in the soil-plant-atmosphere continuum. It is estimated that, by the year 2020 at a global level, 70% of the plant nutrients will have to come from fertilizers with a view to sustain the future world population (Ayoub, 1999). The annual global use of fertilizers will need to be doubled by the year 2030 from about 130 million tonnes in the 1990s (Brown et al., 1997), if the current per capita cereal production is to be maintained (Gilland, 1993). Besides, the anthropogenic N inputs into agricultural systems like N from animal wastes, increased biological N fixation, cultivation of mineral and organic soils and addition of crop residue to the field are also a growing concern. The use of inorganic nitrogenous fertilizers has been increasing in the tropics during the last few decades to enhance soil productivity and crop yield potential. Consequently, the indiscriminate use of both inorganic and organic N fertilizers may cause significantly higher gaseous N losses, particularly nitrous oxide (N_2O) that causes global warming and ozone layer depletion (Bouwman, 1990; Cicerone, 1987; Crutzen, 1981). The main sources of N_2O are cultivated soils, biomass burning, fossil fuels and nitric and adipic acid production. On a molar basis, N_2O is about 250-320 times more effective as an absorber of infrared radiation than CO_2 (IPCC, 1995; Robertson, 1993) and about 25 times more than CH_4 (Murdiyarso, 1998). The atmospheric concentrations of N_2O have increased by 15%

during the last 250 years (Mosier, 1998). The present increasing concentration of N_2O in the atmosphere seems to create a genuine catastrophe on the global climate.

The N_2O emission is a significant biogenic phenomenon in N transformation mechanisms and occurs during both the nitrification and denitrification process. It may be formed by various denitrifiers, nitrifiers and even certain assimilatory nitrate-reducing yeasts and fungi. Nitrification may be a significant source of N_2O through autotrophic microbes in most soils and heterotrophs in aerobic to near-aerobic soils, particularly in soils that are too acidic to support the chemoautotrophic nitrifiers (Anderson et al., 1993; Bremner, 1997). Its production is enhanced in soils having a high mineralization capacity to form NH_4^+ or treated with nitrifiable forms of nitrogen. The N_2O is an obligatory intermediate during denitrification and aerobic bacteria are basically responsible for the process. The dominant denitrifiers are organotrophs because of their versatility and ability to compete for C substrate (Tiedje, 1988). If soils containing nitrate become anaerobic, the availability of organic carbon to enhance the activity of denitrifiers is the limiting factor for the reduction of nitrate. During both processes, a large accumulation of NO_2^--N can be a key compound in N loss processes, forming NO, NO_2 and N_2O (Firestone and Davidson, 1989) because of its low stability in acid conditions (Van Cleemput and Baert, 1984).

The emission of N_2O to the atmosphere from the soil system consists of a series of complex reactions. It is also related to the sequence of enzymatic processes in which the living microbial biomass provides the enzymes and the dead microbial biomass the substrate (Mengel, 1996). The N_2O release depends on the N supplying capacity of soils, which depends mostly on the indigenous soil organic matter, addition of organic residue and the various soil environmental factors viz. moisture, temperature, aeration and pH (Németh and Szebeni, 1987; Szebeni and Németh, 1987). Under aerobic conditions, nitrification is the dominant process for N_2O formation, though a small uptake has been observed in isolated instances in dry soils (Duxbury and Mosier, 1993). It is greater under anaerobic conditions (Firestone, 1982) during denitrification. However, its consumption has also been reported in wet grass pastures (Ryden, 1981). Its production and diffusion are considerable upon irrigation/rainfall events under upland conditions by changing the soil physico-chemical properties or by affecting soil gas diffusivity and microbial activity and subsequent nitrogen gas production and efflux (Delgado and Mosier, 1996; Valente and Thornton, 1993). However, Rosswall et al. (1989) emphasized on the medium to high moisture content, limiting oxygen diffusion, and high mineral-N and high organic-C availability for the production of N_2O from soils.

The application of chemical N fertilizers is a major contribution to N_2O emission from agricultural soils. Addition of organic residue/amendment, preferably N-rich residue, causes considerable release of N_2O. It is estimated that more than 75% of the added N fertilizer is lost from the residue-soil system on a year to year basis if the soil N content remains unchanged (Beauchamp, 1997). In general, N_2O emissions from agricultural land vary from 0.03 to 2.7% of the applied total N fertilizer (Eichner, 1990). However, soil management and cropping systems, and variable rainfall have greater effects on N_2O emission than the type of fertilizer and its fluxes are variable in time and space (Mosier, 1989). Biological nitrogen fixation (BNF) also acts as a source of N_2O as the atmospheric nitrogen fixed by legumes can be nitrified and denitrified in the same way as fertilizer nitrogen (Freney, 1997; Galbally et al., 1992). The contribution from the BNF ranges from 0.5 to 5 kg N_2O-N ha^{-1} yr^{-1} that vary with soils and climatic conditions (Carran et al., 1995; Mosier et al., 1996). However, the fixation and conversion coefficients are still uncertain.

Ultisols, Oxisols and Inceptisols are the dominant soils in Malaysia, where Oxisols and Ultisols occupy about 72% of the total area. They are also the major soils of the tropics and occupy 38.1% of the total land area, where the Ultisols covers 10.6% (Van Wambeke, 1991). Malaysian soils in the upland are mostly weathered and acid with low organic matter content and low CEC. Hence, more and more inorganic and organic N fertilizers are applied to sustain yields through improvement of soil productivity. As a typical humid country in the tropics, this area mostly experiences a good amount of rainfall (2000-2500 mm per annum), which is well distributed, and has a temperature range of 24-34°C throughout the year. These may influence gaseous and leaching losses of N with poor N use efficiency by the crops. Controlled release fertilizer or nitrification inhibitor has the potential to improve N use efficiency by matching nutrient release with crop demand and reducing nitrate release and gaseous losses (Delgado and Mosier, 1996). However, its application is still considered to be uneconomical due to the higher production cost of the fertilizers. Appropriate soil management approaches may be considered better options till now to reduce the emission of N_2O gas - a global concern for the 21st century.

Objectives of the Study

Identification of the processes involved in N_2O production from agricultural systems may take into account also different soils, crops and climates. However, research work has mostly been confined on its emission in the temperate regions. There is only limited information concerning utilization of N from crop residue and animal manure applied to agricultural soils (Mosier et al., 1998a). In the humid tropics, considerable works on rice-ecosystem has been done and very few on the upland agroecosystems, particularly in acid soils. Maize is one of the major crops in the tropics, next to rice and wheat. Groundnut, a leguminous oil crop, occupies a large area next to oil palm, soybean and mustard and has also been cultivated either as monocrop or in rotation. However, information on N_2O emission from a maize-groundnut crop rotation is greatly lacking, particularly under sustainable soil management systems. Therefore, this study was carried out to estimate the emission of N_2O from an upland cropping system applied with both inorganic and organic N (as crop residue/amendment) fertilizers. The following specific objectives are defined:

1. To study the diurnal and temporal variations of N_2O emission, and the annual N_2O release from a maize-groundnut crop rotation under different soil management practices over a one-cycle period.
2. To measure N_2O fluxes under different inorganic and organic nitrogenous fertilizers, and moisture regimes through the laboratory incubation technique using the soil of the experimental field.
3. To evaluate N_2O production under laboratory conditions using different soil types with or without liming and to determine soil factors controlling its production.